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Aspects of high-quality monitoring loudspeakers

PART I

A NEW TWO-UNIT HIGH-QUALITY LOUDSPEAKER

by

H. D. HARWOOD, B.Sc.

S. A. HUGHES

(Research Department, BBC Engineering Division)

PART II

MONITORING-LOUDSPEAKER QUALITY IN TELEVISION SOUND-CONTROL ROOMS

by

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BRITISH BROADCASTING CORPORATION

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BRITISH BROADCASTING CORPORATION

FOREWORD

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This series should be of interest and value to engineers engaged in the fields of broadcasting and of telecommunications generally.

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ASPECTS OF HIGH-QUALITY MONITORING LOUDSPEAKERS

SUMMARY

In Part I of this monograph a description is given of the design and performance of a compact two-unit loudspeaker originally intended for use in mobile control rooms. Both the frequency range and the quality of reproduction are similar to that of the larger studio monitoring loudspeaker type LS5/5 from which this design was developed; the power-handling capacity, whilst less than that of the LS5/5, is quite adequate for the purpose. The new loudspeaker could have a much wider application than that for which it was designed.

Part II describes investigations to determine why the reproduction given by the latest hanging studio loudspeaker type LS5/6 became noticeably coloured when it was suspended above the picture monitors in a television sound-control room, as dictated by considerations of layout. Earlier studio monitoring loudspeakers did not exhibit a comparable increase in coloration when used in this position.

It is concluded that the coloration was due to the build-up of multiple reflections from the walls and windows when the loudspeaker was suspended symmetrically in the corner of the control room, and that the coloration was more noticeable in the case of the LS5/6 primarily because of the higher quality of this loudspeaker. Methods are suggested for reducing this coloration substantially.

PART I

A NEW TWO-UNIT HIGH-QUALITY LOUDSPEAKER

1. Introduction to Part I

In the past, sound monitoring has been carried out in mobile control rooms (MCRs) by means of an adaptation of the LS3/1 outside-broadcast monitoring loudspeaker, mounted on the roof of the van, specially equalized to compensate for the peculiar acoustic conditions.

The sound quality obtained in these circumstances, however, left something to be desired; furthermore, with the advent of the LS5/5 (floor-standing) and LS5/6 (hanging) studio monitoring loudspeakers,[1] whose cabinet volume of $0 \cdot 085$ m^3 was no greater than that of the LS3/1, the earlier loudspeaker became obsolescent and, when the new colour MCRs (CMCRs) were planned, a replacement loudspeaker was called for.

As the sound power required under these condititions is not as high as in a studio control room, consideration was given to a bookshelf-type two-unit commercial loudspeaker; however, an examination of the maximum power output levels capable of being radiated by this loudspeaker showed that it would neither be powerful enough for the purpose, nor have adequate bass response. This report describes the development of a loudspeaker suited to the requirements, and known as the LS3/4.

2. Design Considerations

2.1 *Units*

In the layout of the colour MCRs, the relevant operator (sound mixer) is seated centrally in the working space with the monitoring loudspeaker fixed to the roof approximately $0 \cdot 7$ m from his head. At such a short distance, there would be unacceptable variations in the sound quality with small changes in head position if a loudspeaker utilizing three spaced units (as in the LS5/5) were used. A preliminary consideration showed, however, that with the smaller power requirements it should be possible to design a two-unit loudspeaker with substantially the same characteristics as the LS5/5 (other than maximum power output), thus giving a compact arrangement suitable for close listening.

The response/frequency characteristic of the 200-mm-diameter loudspeaker unit LS2/2 described in Ref. 1 was shown, there, to cover most of the frequency range needed for a small bass unit and calculations indicated that it should have adequate power-handling capacity for an MCR.

It was furthermore decided that the bass end of the frequency range could be extended by changes to the spider and to the surround material without substantially affecting the response at higher frequencies. Since the sound pressures required were not great, the high-frequency end of the spectrum could well be handled by the low-flux-density version of the high-frequency unit used in the LS5/5.

2.2 *Cabinet*

As the loudspeaker was intended to be mounted on the roof of the van, the depth had to be kept small. This clearly favoured a side-by-side arrangement of the two units, and this disposition was also the best from the point of view of sound distribution; in an MCR it is most important to have a good distribution of sound in the vertical plane, because the sound mixer may move his head over an appreciable angle in this plane (the loudspeaker is relatively close) and another listener may be standing behind him. The two units were therefore placed side by side in a horizontal plane and the front panel arranged at an angle to the roof so that the sound mixer was nominally

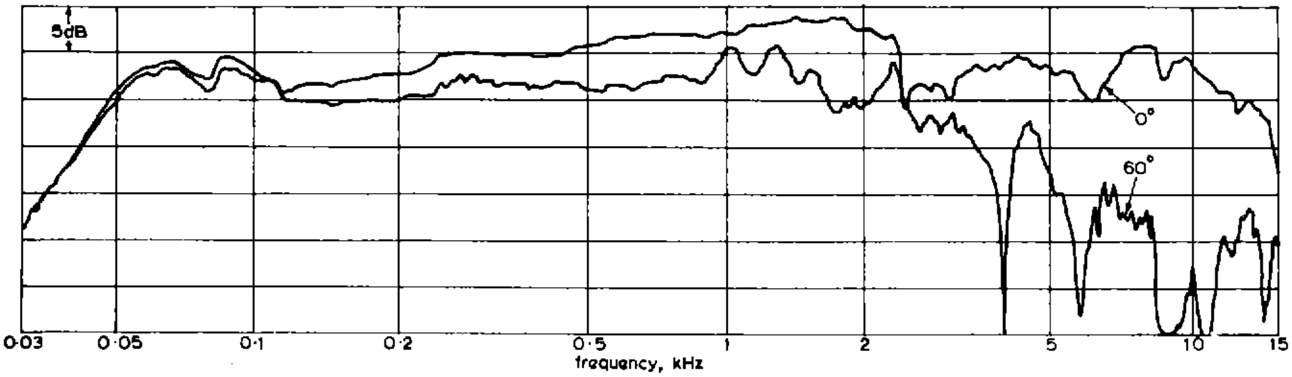

Fig. 1 — *Response/frequency characteristics of unequalized low-frequency unit (with slit) in cabinet. Curves at* 0° *and* +60° *in vertical plane*

on axis. The cabinet was made of oak-faced 9-mm birch plywood, the panels being damped with Mutacell and the air space with polyurethane foam. In an MCR this form of absorbent is greatly to be preferred to the glass-fibre type, as the vibration to which the whole loudspeaker is normally subjected, due to the motion of the vehicle, causes glass fibres to shed sharp particles which can affect the performance of the units; a foamed absorber is also much easier to fix in position and more convenient to handle. The internal volume permissible for the cabinet is 0·06 m^3 with an external volume of 0·07 m^3 (2·1 and 2·5 cu. ft respectively).

3. Design

3.1 *Prototype*

The prototype was required quickly and in the time available (less than four weeks) it was not possible to obtain a more compliant spider or to modify the surround of the low-frequency unit as intended. The crossover network was designed to equalize the low-frequency unit down to 80 Hz, the change to the high-frequency unit provisionally taking place at 3 kHz. The remaining bass loss was made up to the extent of 10 dB by an equalizer placed ahead of the power amplifier and, under these conditions, the axial frequency response was made uniform down to 45 Hz.

The prototype was given a field trial in CMCR No. 1 and it was clear that the sound levels produced were adequate for this application and that the quality of reproduction was good. It was, however, found that, under certain conditions,* overloading of the amplifier took place at the bass. This was not altogether unexpected in view of the conclusions as to bass pre-emphasis arrived at elsewhere.[1]

3.2 *Final Model*

In order to improve the bass response of the low-frequency unit in the final model, the surround material and the spider stiffness were changed as originally intended. Measurements indicated that the surround contributed the main stiffness; the surround not only acts as a centring device but also acts as a mechanical impedance termination for the cone and thereby affects the frequency characteristic of the unit. The unmodified LS2/2 unit uses 0·62-mm-thick (0·025-in.) plasticized p.v.c. known as Nappatex and this was replaced by a surround of the same material and shape but with half the thickness. Measurements showed that although the resonance frequency had indeed been considerably reduced the axial response/frequency characteristic was appreciably inferior to that of the LS2/2. As it was not possible to obtain this material in intermediate thicknesses, other materials had to be used and that finally chosen as the best compromise was a compliant translucent p.v.c. 0·5 mm (0·02 in.) thick; this gave a good axial response and a resonance frequency of the unit in free air of only 33 Hz.

Manufacturers were again approached to obtain more flexible spiders, but without much success. It appears that the one already used in the LS2/2 is as compliant as can reliably be produced in this size, those which are more compliant becoming warped to an unacceptable extent. To extend the bass response still further and increase the power-handling capacity it was therefore decided to use a vented cabinet. Experiments were carried out to determine the optimum vent resonance frequency for the modified unit in the 0·06 m^3 cabinet, the final figure of 40 Hz giving a uniform axial characteristic down to 45 Hz.

As with the LS5/5 loudspeaker, the radiation is made more omnidirectional by employing plates in front of the unit to form a slit. The same spacing as used in that loudspeaker was adopted but, for the reasons given earlier, the slit axis was made horizontal so that the improvement in directional properties was in the vertical plane. The response/frequency characteristics of the unequalized, low-frequency unit under these conditions at 0° and +60° to the axis are shown in Fig. 1. The unit has been coded LS2/4 to distinguish it from the unmodified unit LS2/2 used in the LS5/5 loudspeaker.

Consideration of the off-axis characteristics indicated that a crossover to the high-frequency unit at about 3 kHz would be required; as expected, this is the same frequency as that used for the upper crossover in the LS5/5 loud-

* e.g. with input signals accompanied by excessive wind noise.

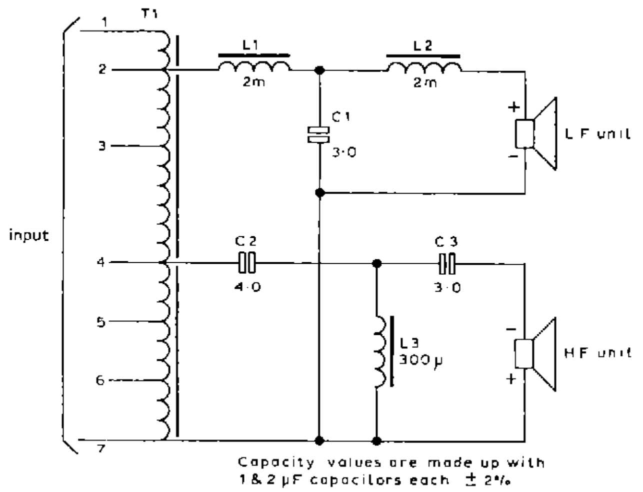

Fig. 2—Circuit of the crossover network

speaker. Crossover networks similar to those for the LS5/5 were used, and are shown in Fig. 2. As the sensitivities of individual low- and high-frequency units were known to vary from sample to sample, an auto transformer with 1 dB tappings was used to enable the relative power levels fed to the units to be adjusted without having to change the crossover components. The networks were designed to equalize the overall axial response/frequency characteristic at the same time as performing their nominal task.

4. Performance

4.1 *Listening Tests*

Listening tests were carried out on the completed loudspeaker and the results were in general satisfactory. There were, however, some signs of a lower-middle coloration below the frequency at which the 200 mm unit is used in the LS5/5. Treating the cone with a second layer of p.v.a. Plastiflex type 1200P removed the coloration without seriously affecting the response/frequency characteristic; the small effect which occurred was compensated for in the crossover network. The voltages applied under these conditions to the two units are shown in Fig. 3. It should be noted that the function of securing the required equalization of the units at the same time as the crossover characteristics has been secured with a very economical use of components.

4.2 *Response/Frequency Characteristics*

The response/frequency characteristics of the complete loudspeaker on the axis and at +60° in the vertical plane are shown in Fig. 4. It will be seen that the response is as extended as that of the LS5/5 although of course the power-handling capacity is somewhat lower.

4.3 *Overload Performance*

Harmonic and intermodulation distortion measurements were made on the axis, for a sound level of 1 N/m² at

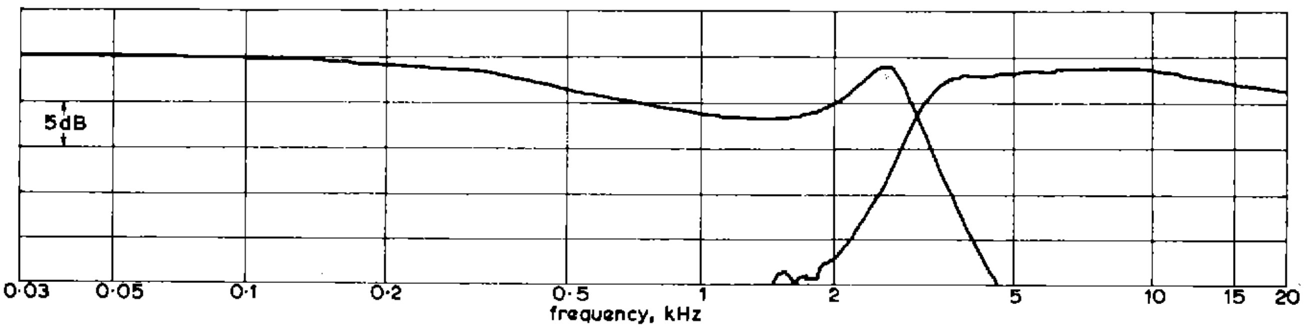

Fig. 3 — Voltages applied to l.f. and h.f. units

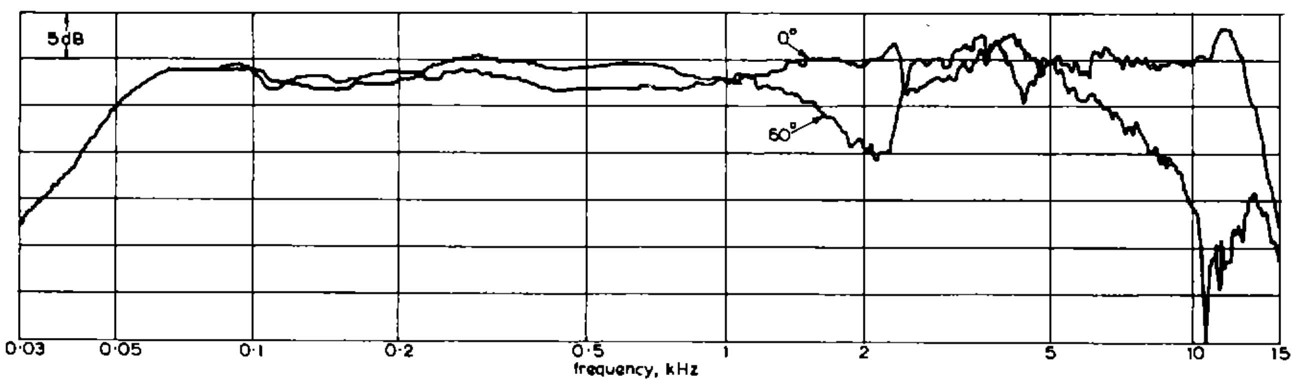

Fig. 4 — Response/frequency characteristics of complete loudspeaker. Curves at 0° and +60° in vertical plane

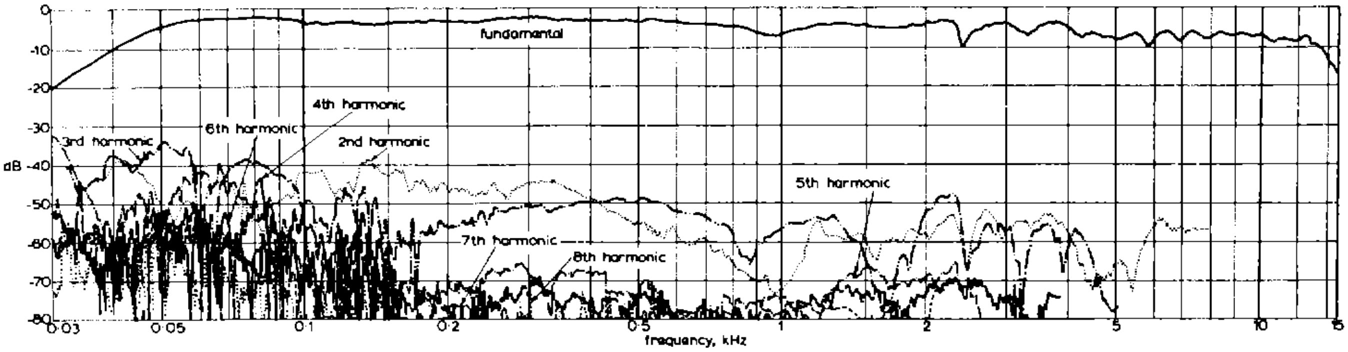

Fig. 5 — Measurements of harmonic distortion for a sound level of 1 N/m^2 *at* 1·5 *m on axis*

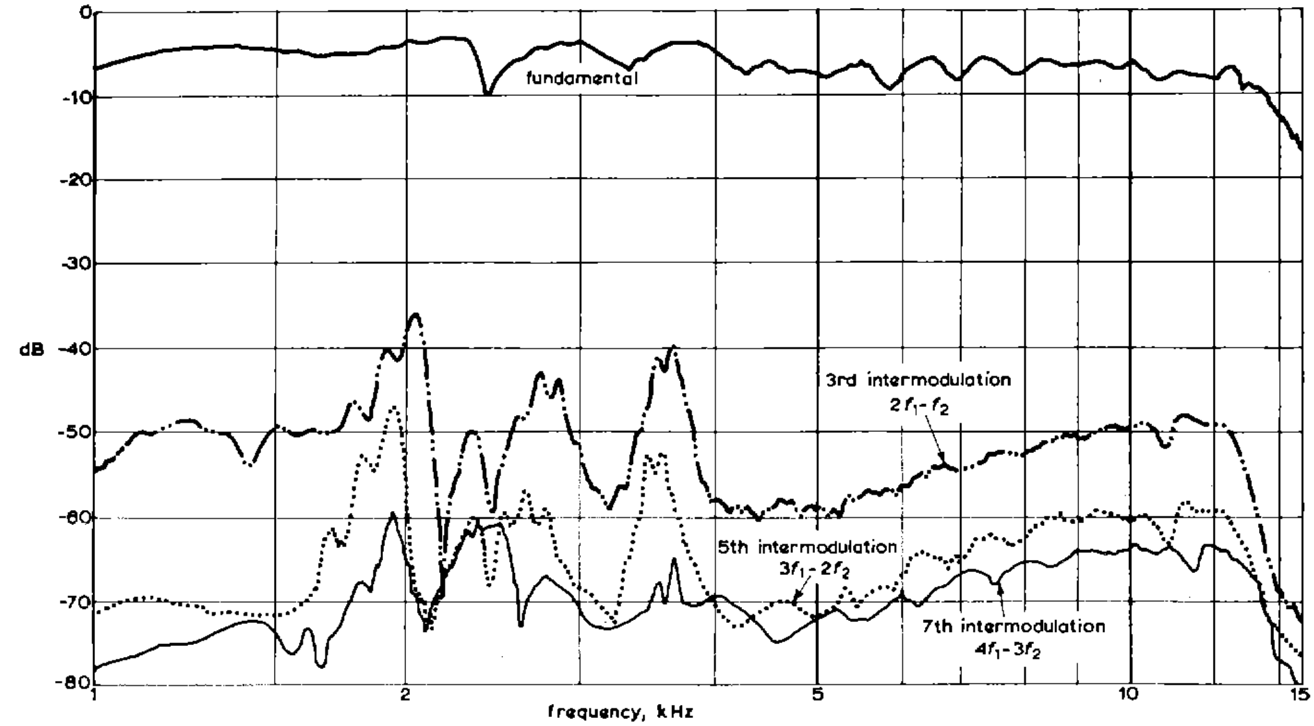

Fig. 6 — Measurements of intermodulation distortion with frequencies f_1 and f_2 and a sound level of 1 N/m^2 *at* 1·5 *m on axis*

a distance of 1·5 m, and the results are given in Figs. 5 and 6. These test results are strictly comparable with those obtained with the LS5/5 loudspeaker, see Figs. 32 and 33 of Ref. 1. It is noteworthy that even at this sound pressure the levels of distortion are of the same order as those from the LS5/5.

The maximum sound level of a pure tone which the loudspeaker can produce at a distance of 1 m is about +4 dB with respect to 1 N/m^2, that is about 6 dB less than that of the LS5/5, the limitation being due to overheating of the voice coils. With a more powerful amplifier it is estimated that with typical programme a midband sound level of +10 dB with respect to 1 N/m^2 could be produced at this distance before acoustic overloading of the units occurred. This level is 5 dB above that capable of being radiated by the bookshelf-type loudspeaker mentioned in Section 1; moreover the undistorted output at 50 Hz of the LS3/4 is +23 dB above that of the bookshelf type.

4.4 *Impedance*

The modulus of the impedance of the loudspeaker is shown in Fig. 7; the nominal rated figure is 25 ohms.

4.5 *Reproducibility of L.F. Units*

Eight low-frequency cones were made so that Equipment Department could produce loudspeakers for the remainder of the initial order. The spread in axial frequency characteristics is given in Fig. 8 and will be seen to be very small.

4.6 *General Comments*

The appearance of the loudspeaker with and without

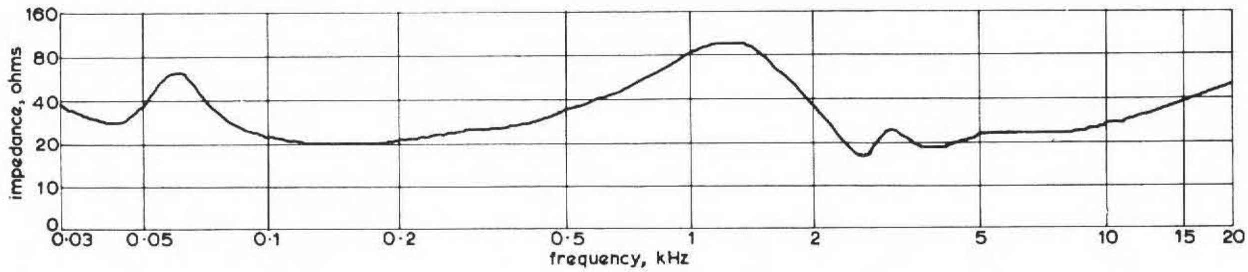

Fig. 7 — Modulus of impedance

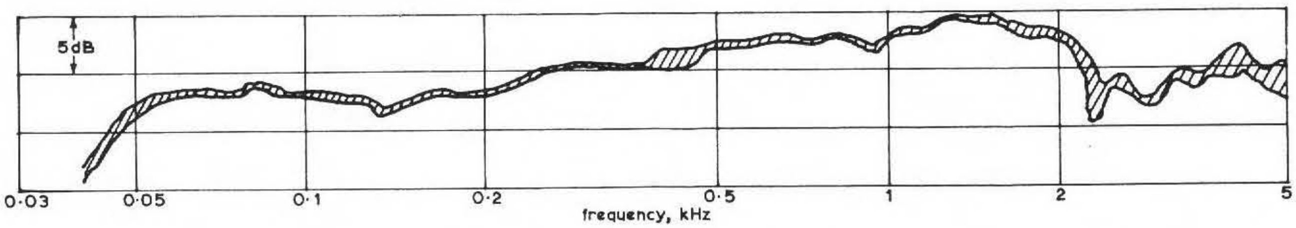

Fig. 8 — Spread in axial response/frequency characteristics of eight unequalized low-frequency units

the front Tygan grille is shown in Fig. 9.

Although this loudspeaker was developed for a specific location in a television mobile control room, the performance makes it suitable for many other situations in which high quality combined with only moderate power output is required. A stereo pair has been made for use in a transcription recording unit (TRU) vehicle with normal listening distance and gives good image resolution. The control cubicles of most talks studios would be adequately served by a loudspeaker of this design, at a considerable saving in expense compared with a full-sized monitoring loudspeaker; for this purpose a differently shaped cabinet might be more acceptable on aesthetic grounds, but the necessary alterations could be made without difficulty. A rectangular cabinet 63·5 cm by 30·5 cm by 30·5 cm would have the required external volume of $0 \cdot 07\ m^3$.

5. Conclusions

Knowledge gained in the development of the studio monitoring loudspeakers (LS5/5 and LS5/6) has made possible the production of a very much smaller loudspeaker of similar sound quality with a power output adequate for use in colour television mobile control rooms.

This loudspeaker would be equally suitable for use in radio outside broadcasts and in the many studio control rooms where the quality but not the available power of a full-sized monitoring speaker is required. As the manufacturing cost is only about half that of a full-sized studio loudspeaker, a considerable saving would result. The LS3/4 loudspeaker is now being produced commercially for the BBC.

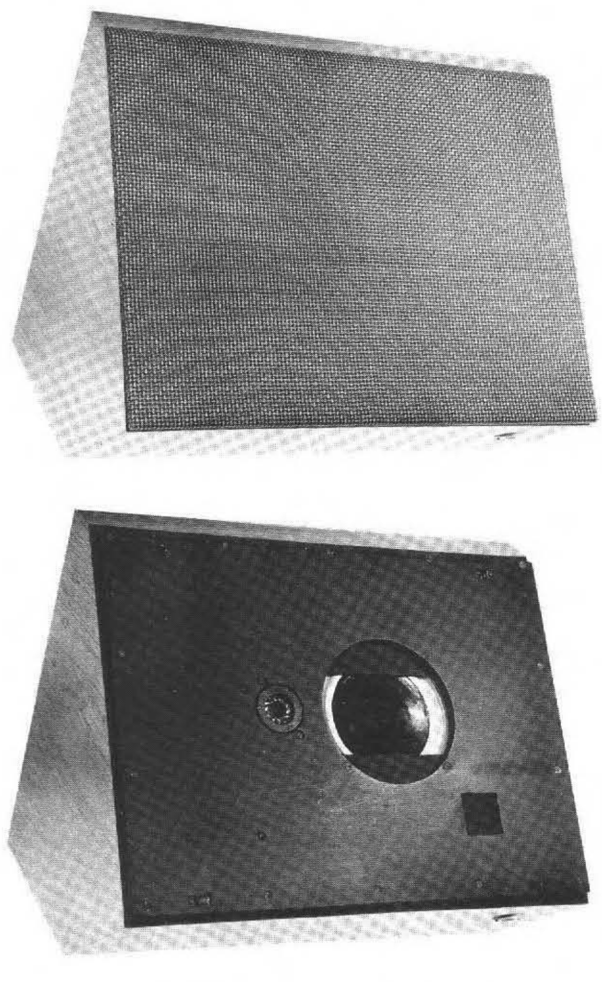

Fig. 9 — Appearance of loudspeaker

Part II

MONITORING-LOUDSPEAKER QUALITY IN TELEVISION SOUND-CONTROL ROOMS

6. Introduction to Part II

The most convenient position for the monitoring loudspeaker in a television sound-control room is above a group of picture monitors. This position is largely a forced choice because the listener's strong directional sense in the horizontal plane discourages the use of positions at one side or the other of the picture monitors while the space below is normally screened by the control desk and other obstacles. The monitoring loudspeakers developed by Research Department have, by deliberate Corporation policy, been designed to stand or hang as independent units as this arrangement allows the greatest flexibility in their use. In a sound-control cubicle for radio the loudspeaker usually stands on the floor within a few feet of the Studio Manager, clear of the desk and other obstacles. The layout in television control rooms favours the use of a freely hanging unit, usually near to a corner or edge of the ceiling.

The hanging version of the LSU/10 studio monitoring loudspeaker (introduced in 1958 and having a cabinet volume of $0 \cdot 28$ m^3) performed reasonably well with the aid of a bass lift, but with the completion of Television Centre and the introduction in 1959 of the hanging loudspeaker LS5/2A*, with a cabinet volume of $0 \cdot 14$ m^3, it was found that loudspeakers which were perfectly satisfactory in most circumstances sounded less satisfactory when hung in a corner of a sound-control room. However, minor changes in the acoustic treatment of the control rooms had a useful effect in restoring the quality of the loudspeaker sound.

In 1965, however, the LS5/5 floor-standing loudspeaker and its hanging version, the LS5/6 (both with a cabinet volume of $0 \cdot 085$ m^3), were introduced. Service trials of prototype LS5/6 loudspeakers in Television Centre sound-control rooms have revealed a greater change in quality of reproduction when the loudspeaker is hung in the corner from when is stands free. The changes which could possibly make the new loudspeakers more sensitive to environment are (*a*) smaller size and hence more omnidirectional radiation, and (*b*) the improved quality of reproduction and in particular the greater inherent freedom from coloration, due to the use of highly damped cone material, which makes the colorations introduced by corner-mounting more obvious subjectively.

The deterioration in quality is generally agreed to affect particularly the frequency range from about 100 to 400 Hz, which becomes weak or uneven, and higher middle frequencies which become coloured and apparently more reverberant. The effects on the lower range are particularly noticeable on polyphonic organ music, the separate parts of which change in relative level according to their positions in the scale.

* The floor-standing version of this loudspeaker was the LS5/1A.

7. Preliminary Investigation

Three hypotheses have been suggested to explain the effect:

(1) that the release of load on the base of the cabinet when the loudspeaker is lifted from its plinth and hung from the suspension allows the cabinet to vibrate more freely, thus colouring the radiated sound at a series of resonance frequencies;

(2) that the quality change is entirely due to interference effects between the direct sound from the loudspeaker units and sound reflected from the walls and ceiling in the neighbourhood of the loudspeaker; and

(3) that the effects are psychological in origin, and associated with the unnatural or unaccustomed direction of the sound reaching the listener. This explanation is more difficult to examine in objective terms than the other two and, if it were true, a cure would be much more difficult. It was, therefore, decided that this should be regarded as a 'long-stop' hypothesis, to be invoked only if physical explanations were found to be inadequate.

Preliminary work was therefore directed towards examination of the first two possibilities. To test the first, the suspension of an LS5/6 was replaced by ropes attached to the suspension points and passing over pulleys so that the loudspeaker could be lowered on to a plinth standing on the floor, or raised at will.

Listening tests both directly and from recordings were made, using speech and music programme material, with the loudspeaker resting on the plinth and raised just to clear it. These tests failed to show any change in quality whatever when the loudspeaker was just clear of the cabinet-base, and it was therefore concluded that suspension *per se* as opposed to plinth mounting was not a significant factor.

If interference from reflections were the cause of the quality changes, it would seem likely, on the basis of past experience,[2] that their separate amplitudes are not more than 4 dB below that of the direct sound. The steady-state characteristic at a microphone in the listening position would therefore have a series of easily detected fluctuations. This was confirmed in a series of experiments carried out in the free-field room using hardboard flats to simulate the neighbouring surfaces in a television control room.

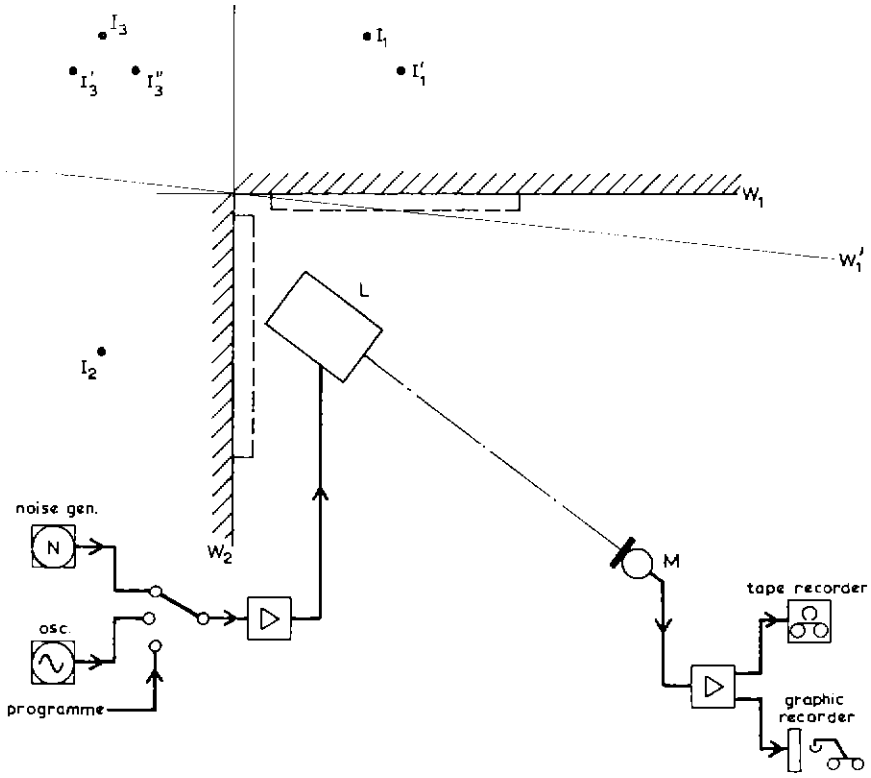

Fig. 10 — Experimental arrangement
L = Loudspeaker LS5/6 W_1, W_2 = Walls I_1–I_3 = Images
M = Microphone C12 with cardioid characteristic

The existence of path difference between different components of the sound was confirmed by means of correlogramms obtained from the Research Department correlator.[3]

8. Study of Reflections from Surfaces Close to a Loudspeaker

Fig. 10 shows the arrangement used for experiments to test the hypothesis that the deterioration of quality was caused by reflections. For clarity it is shown in two dimensions only but the extension to three dimensions is fairly simple. W_1 and W_2 are two walls of a room, meeting at a corner in which a loudspeaker is hung, and for simplicity, the centre of the high-frequency unit is taken as the effective position of the loudspeaker. I_1, I_2 are images of this point in the two walls, W_1 and W_2, and there is a third image I_3 (the 'corner image') formed by reflections from both walls. If the walls are not at right angles, as shown by the alternative position W_1' of W_1, I_3 will be split into two images I_3' and I_3'', but for moderate divergence from a rectangular room, they will be close enough to behave as a single image at the wavelengths concerned. The ceiling will produce one further image I_4 vertically above L, by direct reflection and will contribute a further pair of images I_5 (vertically above I_1) and I_6 (vertically above I_2) and a third new image I_7 (vertically above I_3). All these images will cause interference effects with the direct sound.

In the tests the loudspeaker could be fed with random noise ('pink' noise with equal power per octave), with pure or warbled tone,* or with programme from recordings. The output of the microphone was fed to a magnetic tape recorder and in parallel to a graphic recorder ganged to the tone generator so that steady-state transmission diagrams could be rapidly produced.

Fig. 11 shows the steady-state characteristics with the loudspeaker in a symmetrical position in the corner of a room with adjustable acoustics, (in fact the Acoustic Treatment Room or ATR). All treatment had been removed from the neighbourhood of the corner and the loudspeaker was oriented so that the axis of the high-frequency unit passed through a measuring microphone 1·3 m above floor level. Fig. 12 was obtained from similar tests in the listening room with the loudspeaker standing on a plinth in an unsymmetrical position with respect to the walls of the room. These curves, of course, represent the combined effect of room and loudspeaker and should in no way be confused with those of the loudspeaker alone.

Compared with Fig. 12, Fig. 11 shows a series of broad maxima and minima at low and middle frequencies, the

* Pure tone frequency-modulated over a range of ± 63 Hz at a rate of 10 times per second.

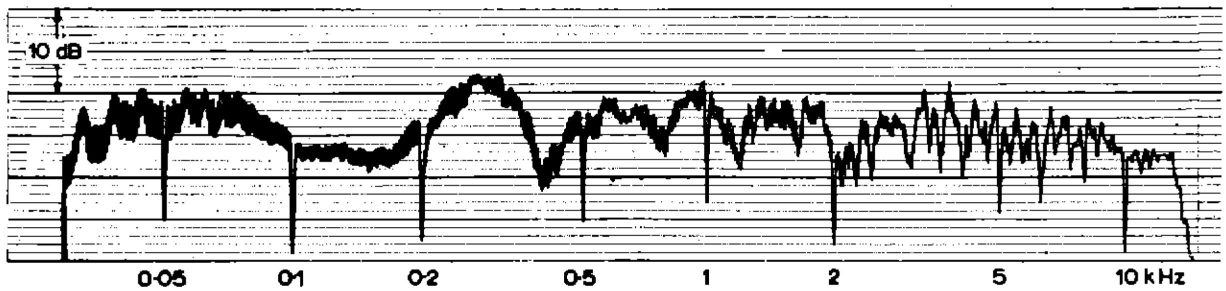

Fig. 11 — *Response/frequency characteristic. Loudspeaker symmetrically placed in upper corner of ATR* (*warble tone*)

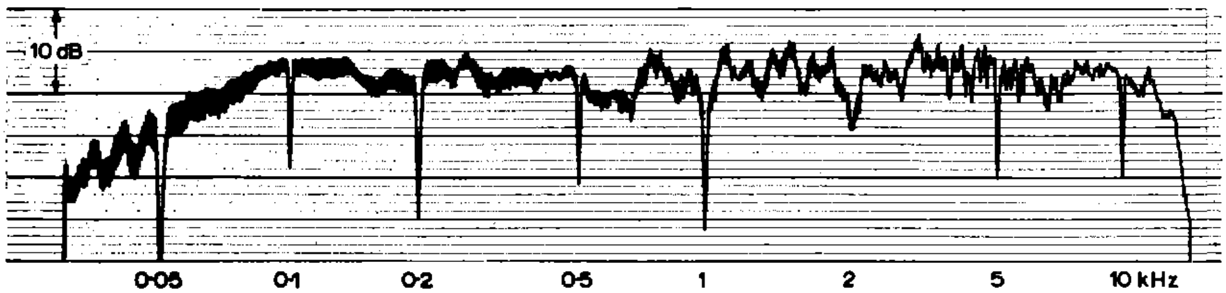

Fig. 12 — *Response/frequency characteristic. Loudspeaker in Quality Listening Room* (*warble tone*)

maxima occurring at 50, 280, 630, and 950 Hz. A smoothed curve drawn through the middle of the trace (ignoring the excursions caused by the frequency modulation of the tone) indicates peak-to-trough variations up to 11 dB. At high frequencies, also, there are differences of a similar kind. Listening tests on recordings of programme and pink noise from the ATR showed that there was an easily audible coloration just below 300 Hz on both random noise and speech, agreeing with the main peak in this region. There is a clear suggestion, therefore, that the colorations at lower frequencies are associated with peaks in the steady-state characteristic.

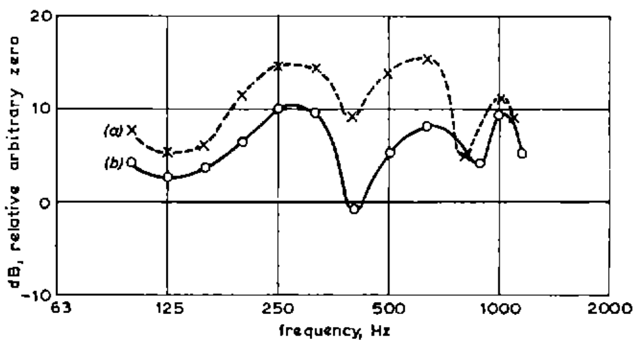

Fig. 13 — *Response/frequency characteristics from loudspeaker in corner of ATR*

(*a*) Calculated from direct and strongest three images
(*b*) Smoothed from Fig. 11

Fig. 13, curve (*a*), shows the expected resultant of the sound pressure from the loudspeaker and its images, calculated by ordinary vector summation from the following data and assumptions:

(1) Measurements of the positions of the loudspeaker and microphone in the ATR.
(2) The assumption of a value of 90 per cent for the reflection coefficient at the walls, with no significant phase change on reflection.
(3) The assumption that the two images lying directly behind the loudspeaker could be neglected. One of these is formed by two successive reflections and the other by three, and both are formed by radiation inside a comparatively small solid angle at the back of the loudspeaker where the radiation in any case is relatively low.

Fig. 13, curve (*b*), is a smoothed reproduction of a portion of Fig. 11. The similarity between the two curves is sufficiently close to confirm that interference by reflections from the surfaces surrounding the corner is an adequate explanation of the low-frequency effects.

As the frequency is increased, the fluctuations of Fig. 11 vary in depth owing to the interaction of images at several different distances, making calculation very uncertain; but from 3 kHz upwards a more regular pattern asserts itself, probably because the radiation is mainly forwards and only the three primary images in the two walls and the ceiling are effective. The high-frequency fluctuations appear to be harmonically related to 270 Hz.

Fig. 14 is the steady-state characteristic, for comparison with Fig. 11, obtained after moving the loudspeaker from its symmetrical position by 45 cm parallel to one wall. In this position the path lengths from the two primary images to the microphone are different and the fluctuations are accordingly reduced at low frequencies. There are still large fluctuations above 500 Hz, however, presumably caused by coincidences in frequency between the two series

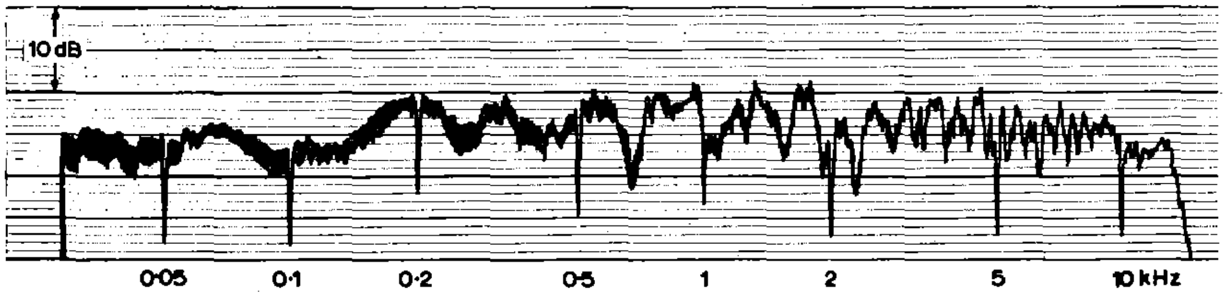

Fig. 14 — *Response/frequency characteristic. Loudspeaker in unsymmetrical position in ATR* (*warble tone*)

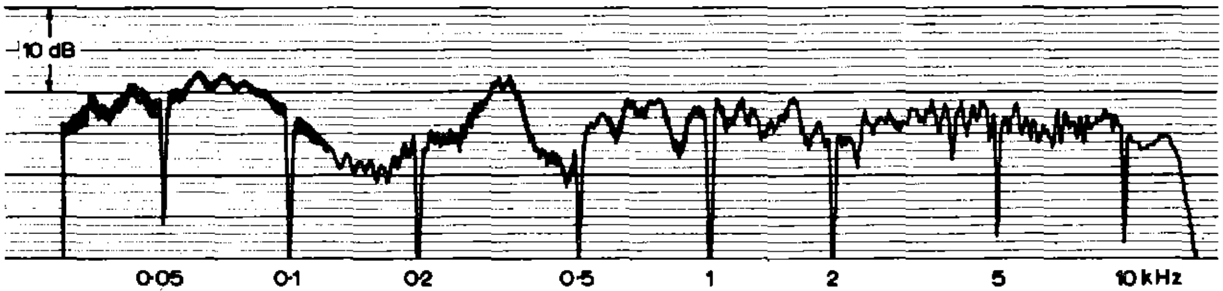

Fig. 15 — *Response/frequency characteristic. Loudspeaker symmetrically placed in corner of floor of ATR* (*warble tone*)

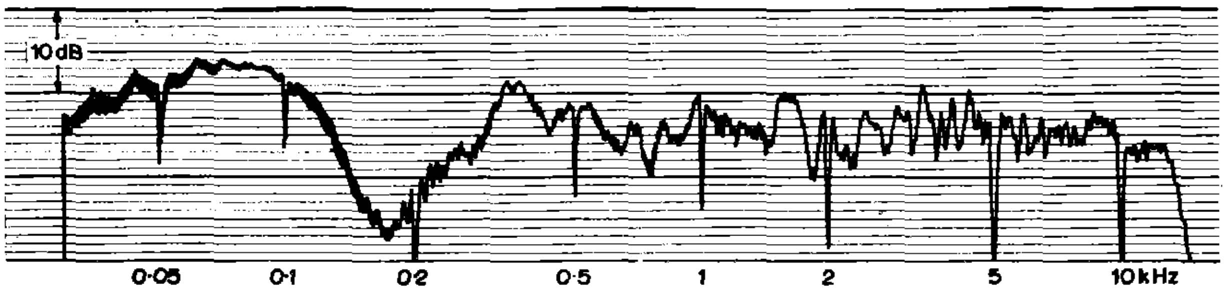

Fig. 16 — *Response/frequency characteristic. As Fig.* 15, *but loudspeaker touching walls and floor* (*warble tone*)

of harmonics associated with the two separate path lengths.

9. Discussion

The evidence in this monograph shows that interference by reflections with the direct sound is sufficient to explain the measurable effects of the loudspeaker environment. It is also consistent with the subjective observations which were the starting-point of this investigation. It may be a matter of surprise that such large fluctuations on all the curves do not make the loudspeakers unacceptable in any situation other than a free-field room, but it should be emphasized that it is common observation that one does not normally notice the equally great fluctuations due to room modes which equally affect the sound of live speech in a room. The faculties of binaural hearing and central analysis give considerable relative weight to the direct sound.

Hitherto the loudspeaker has been assumed to be near a ceiling edge or corner; Fig. 15 corresponds to Fig. 11 when the loudspeaker is placed symmetrically near a corner of the floor. Low-frequency peaks and troughs have much the same frequencies and amplitudes in Fig. 15 as in Fig. 11. High-frequency fluctuations in Fig. 15 are less, as is to be expected since there is usually a carpet on the floor. This accounts for the subjective impression that a ceiling position spoils loudspeaker quality more than the corresponding floor position.

The effects of small displacements of the loudspeaker from this position were also checked. Fig. 16 shows how a displacement towards the apex of the corner greatly increases the amplitude of the low-frequency fluctuations; tests showed that withdrawing the loudspeaker from the corner and moving it away from a symmetrical position both produced progressive reductions in the fluctuations.

Assuming that the effects are entirely due to interference there are thus three alternative methods for improving reproduction in these circumstances.

(1) To absorb sound falling on the side walls and ceiling. This will require a highly efficient absorber working over the entire audio bandwidth applied to a suitable area round the loudspeaker position. A suitable type is a partitioned air space 15 cm deep closed by 5 cm of dense rockwool and a fabric or

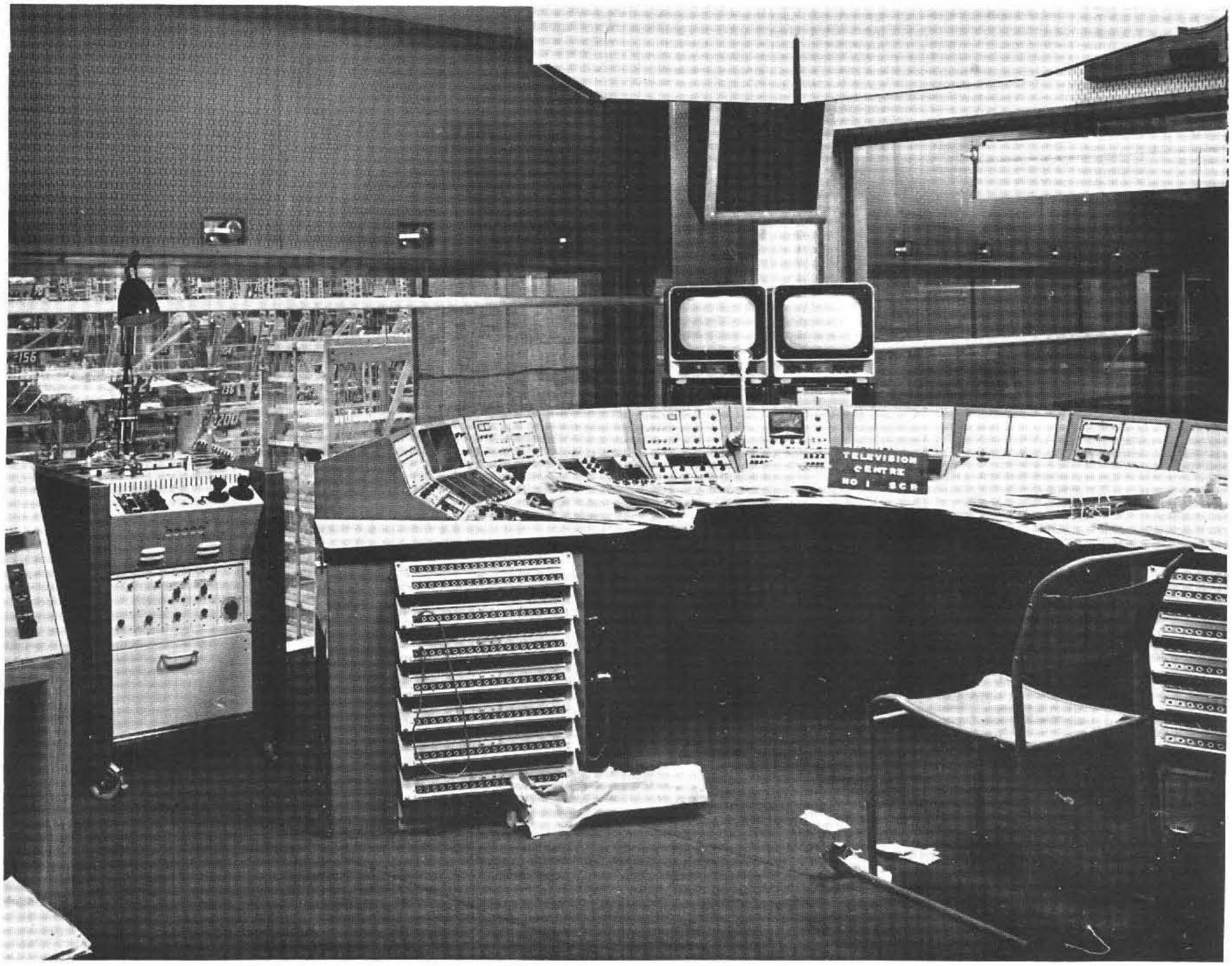

Fig. 17 — Position of the LS5/2 loudspeaker in Television Centre Studio 1 sound-control room

highly perforated cover. The probable cost would be £40 per control room.

(2) To use unsymmetrical loudspeaker positions, preferably chosen to eliminate the major fluctuations. Since large fluctuations are almost bound to occur due to coincidences in some part of the spectrum, the provision of some sound absorbers will probably also be necessary. As low-frequency fluctuations may almost certainly be suppressed by unsymmetrical mounting, it may be sufficient to use absorbers which are efficient only at middle and high frequencies and these will be shallower than full-range types. The price difference would be small, however, since the deep wide-band absorbers are available as prefabricated units 61 cm by 61 cm in area and are in production for local radio-broadcasting studios.

(3) To alter control-room layouts so as to place the monitoring loudspeaker in a more favourable position. This can be decided only when the control room is planned.

10. Application

An opportunity to test out these conclusions arose in the sound-control cubicle of Studio 1 in Television Centre. A loudspeaker type LS5/2, which it was agreed gave a high quality of reproduction when near the floor, gave an objectionable quality described as 'tunnelly' when hung above the television monitors in a corner of the room. The position of the loudspeaker is shown in Fig. 17 and it is evident from the picture that very little can be done in the way of adding absorbent at the sides of the loudspeaker without covering large areas of window. The wall area available behind the loudspeaker was treated in this way but the quantity of absorbent involved was so small that it was not surprising that very little benefit resulted.

A response/frequency curve was taken with a cardioid-type microphone at the edge of the control desk facing the

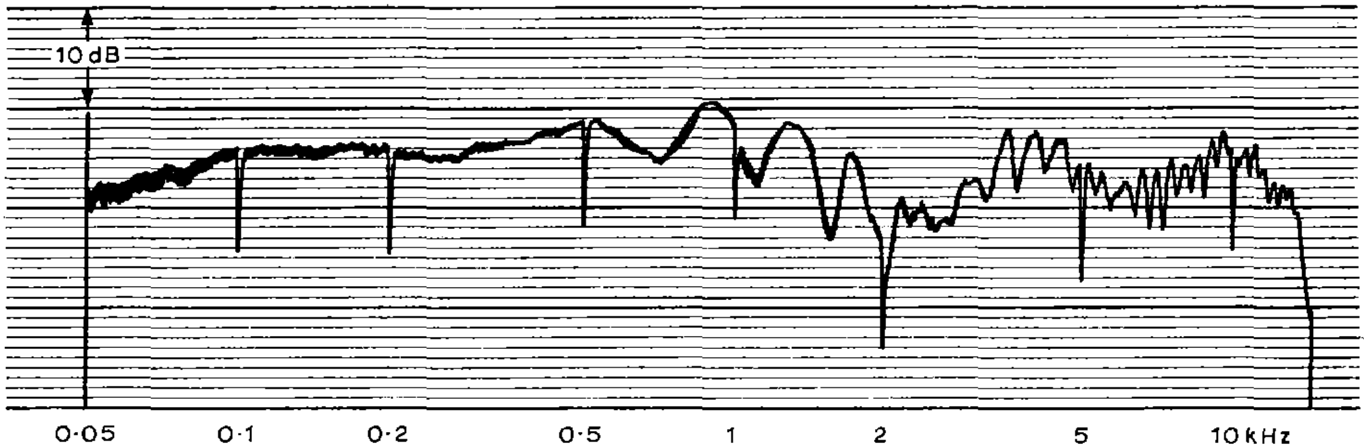

Fig. 18 — *Response/frequency characteristic. LS5/2 in upper corner of Television Centre Studio* 1 *sound-control room as shown in Fig.* 17. *Cardioid microphone characteristic.* (*Warble tone.*)

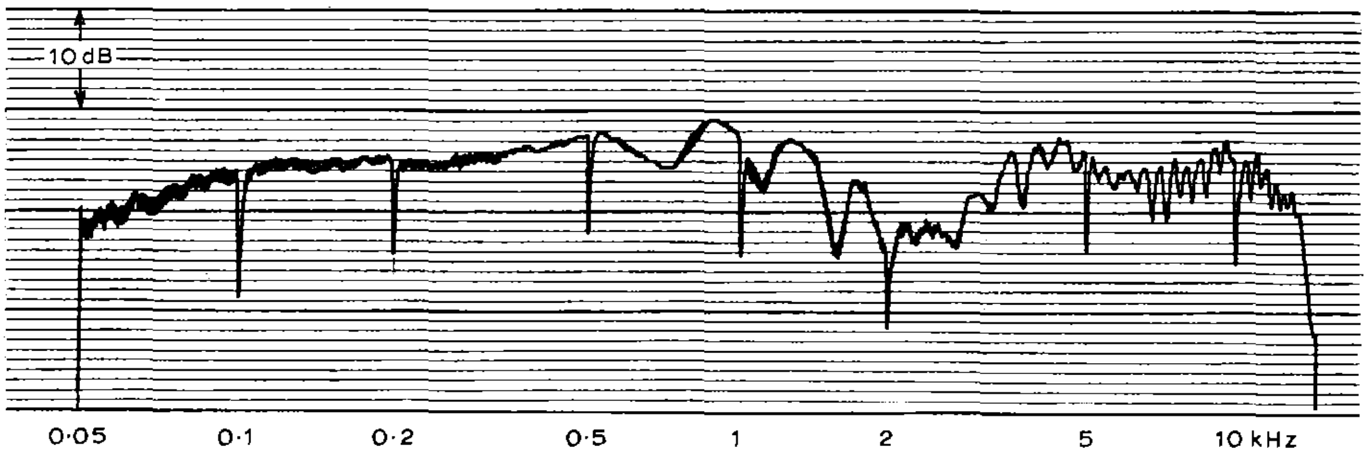

Fig. 19 — *Response/frequency characteristic. LS5/2 in upper corner of Television Centre Studio* 1 *sound-control room as shown in Fig.* 17. *Figure-of-eight microphone characteristic.* (*Warble tone.*)

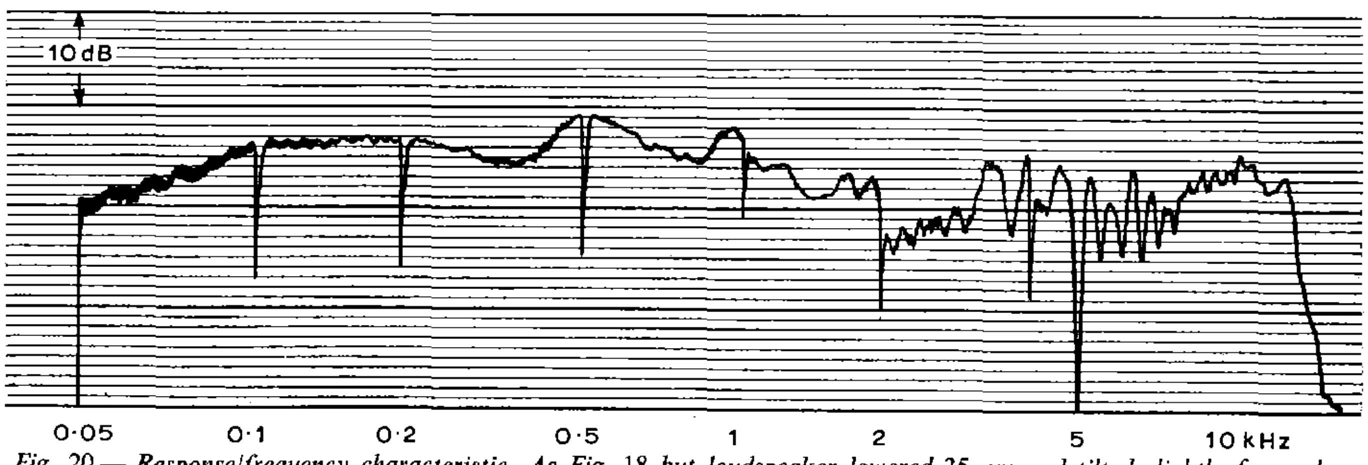

Fig. 20 — *Response/frequency characteristic. As Fig.* 18 *but loudspeaker lowered* 35 *cm and tilted slightly forward.* (*Warble tone.*)

axis of the loudspeaker and with warbled tone applied as in the earlier curves. The result is shown in Fig. 18 and the expected irregularities are evident in the 500 Hz to 2 kHz region. To check that the irregularities were not due to interference from reflection off the desk the measurement was repeated with a figure-of-eight polar characteristic, the null being directed towards the desk. The results are shown in Fig. 19 and are substantially the same.

It was noted that the sound quality varied rapidly with distance from the desk and indeed throughout the whole room, although the impression of 'tunnelliness' persisted everywhere.

Since the first suggestion of improving the sound quality was inapplicable the second was tried. The loudspeaker was lowered from the ceiling about 35 cm until it touched the monitors and the angle adjusted until it again faced the sound supervisor.

It was immediately obvious on listening that the sound quality had greatly improved in the normal monitoring position and furthermore that it did not vary substantially with position and was acceptable throughout the whole room.

A further response/frequency curve was taken at the monitoring position with the microphone in the cardioid condition and the resulting curve is shown in Fig. 20. It will be noted that the irregularities in the 500 to 2 kHz region have almost disappeared, and that even those at high frequencies have been somewhat reduced. As a matter of interest it was not possible even on careful listening to attribute any effect to these latter irregularities and it appears therefore that the ear is more tolerant in this frequency range.

11. Conclusions

The degradation in quality observed when a high-quality monitoring loudspeaker is used in a reflecting corner is satisfactorily explained by interference between the direct sound and that reflected from the surfaces forming the corner.

Three methods of improvement are proposed, and it is shown that in practice the cheapest at least is very effective. Approximate costs are indicated where possible so that users may decide which course should be further pursued.

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